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14. ABSTRACT
Forbush decreases (FDs) in neutron monitor (NM) counting rates are caused by enhanced magnetic fields in interplanetary shocks and solar ejecta that shield the Earth from galactic cosmic rays (GCRs). The solar origins of those ejecta can be observed as coronal mass ejections (CMEs) in coronagraphs, but their propagation through interplanetary space near or past the Earth has not been previously observable. The Solar Mass Ejection Imager (SMEI), launched into polar Earth orbit in January 2003, now allows us to search for the white light signatures of interplanetary CMEs (ICMEs) responsible for FDs. SMEI is unique in that it can monitor the progress of CMEs through the inner heliosphere out to distances beyond 1 AU and distinguish those which hit the Earth from those that do not. For comparison with SMEI observations, we selected all FDs of $\geq 2\%$ observed with the Oulu, Finland, NM. We find an excellent association of SMEI CMEs with those FDs and for each of the associated SMEI CMEs a good candidate associated LASCO CME was also found. The SMEI observations provide information on the approximate spatial locations and trajectories of large ICMEs that may result in FDs and hence can be useful as a space weather tool.

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Imaging Interplanetary Disturbances Causing Forbush Decreases

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Forbush decreases (FDs) in neutron monitor (NM) counting rates are caused by enhanced magnetic fields in interplanetary shocks and solar ejecta that shield the Earth from galactic cosmic rays (GCRs). The solar origins of those ejecta can be observed as coronal mass ejections (CMEs) in coronagraphs, but their propagation through interplanetary space near or past the Earth has not been previously observable. The Solar Mass Ejection Imager (SMEI), launched into polar Earth orbit in January 2003, now allows us to search for the white light signatures of interplanetary CMEs (ICMEs) responsible for FDs. SMEI is unique in that it can monitor the progress of CMEs through the inner heliosphere out to distances beyond 1 AU and distinguish those which hit the Earth from those that do not. For comparison with SMEI observations, we selected all FDs of ≥ 2% observed with the Oulu, Finland, NM. We find an excellent association of SMEI CMEs with those FDs and for each of the associated SMEI CMEs a good candidate associated LASCO CME was also found. The SMEI observations provide information on the approximate spatial locations and trajectories of large ICMEs that may result in FDs and hence can be useful as a space weather tool.

1. Introduction

SMEI is an instrument designed to detect and forecast the arrival of coronal mass ejections (CMEs) and other heliospheric structures which are moving towards the Earth [1]. The instrument contains three CCD cameras, each with a field of view of 60° x 3°, which are mounted onto the spacecraft such that they scan most of the sky every 102-min orbit. To exclude light from the solar disk, a baffle system allows sky viewing only to within about 20° of Sun center. The detectors are sensitive over the optical waveband, and the sensitivity is adequate to detect changes in sky brightness equivalent to a tenth magnitude star in one square degree of sky. To detect large CMEs in the SMEI field of view, stellar images and the signal from the zodiacal dust cloud are subtracted from the sky images. The SMEI instrument and mission are described in [2] and [3]. SMEI was launched 6 January 2003 on the Coriolis spacecraft into a Sun-synchronous polar orbit. Since launch SMEI has observed over 140 CMEs, of which at least 6 were Earthward (halo) CMEs (Figure 1).

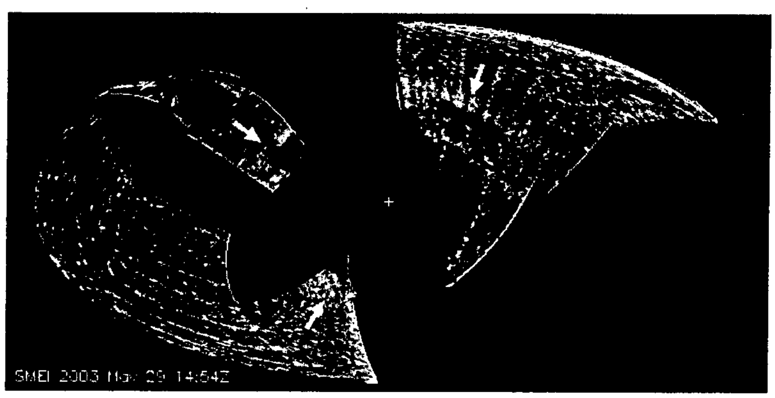

Figure 1. First Earth-directed CME seen by SMEI on 28-29 May 2003 [4]. The image format is an all-sky Aitoff projection in solar ecliptic coordinates with 1° x 1° pixels and the Sun at the center. The data gaps are due to bright objects or energetic particle fluxes. White arrows indicate the position of the CME.

Forbush Decreases (FDs) are transient decreases in the counting rates of GCRs that last typically for about a week. There are two basic types [5] of FDs. The first consist of recurrent decreases, with gradual onsets and more symmetric profiles. These are often associated with corotating interaction regions in the solar wind [6]. FDs of the second type are marked by sudden onsets, reaching maximum depression in about a day, often in two stages [5], and followed by a gradual recovery. In both cases it is understood that the decreases in cosmic ray intensities result from large-scale (≥ 0.1 AU) increases in the interplanetary magnetic fields that modulate the scattering and convection of the GCRs [7,8,9]. Note that the gyroradius of a 10-GeV proton in a 10 nanotesla field is 0.02 AU. GCR fluxes at 1 AU have generally been well anticorrelated with the occurrence rates of CMEs observed at the Sun [10] or at 1 AU [7]. In several specific cases [11,12,13] the GCR variations have been used to model the structures of CME magnetic flux ropes.

It would be useful to be able to forecast FDs, as we learn to use white light CME observations with coronagraphs and SMEI to forecast geomagnetic storms. Since we can't remotely observe the approaching interplanetary magnetic field features that lead to FDs, we want to determine whether observations of heliospheric CMEs may be useful for forecasting FDs. Interplanetary CMEs are characterized by enhanced magnetic fields and often preceded by turbulent fields, which may cause FDs by deflections and scattering, respectively. However, enhanced pressures in CMEs may cause super-radial expansions [14] that decrease their ambient densities and thus could cause many CMEs to become undetectable in SMEI observations of the inner heliosphere. Here we explore the possibility that SMEI observations of CMEs can be useful in predicting FDs at 1 AU.

2. Data Analysis

We use neutron monitor records from Oulu, Finland to search for FDs over the period March 2003 through May 2005. That station is located at a high geographic latitude of 65° and has a low cutoff rigidity of 0.78 GV. We selected as FDs all ≥ 2% decreases in counting rates for which the maximum decrease occurred within 3 days of the onset. Figure 2 shows the Oulu Neutron Monitor counting rate profile for the two FDs on 22 and 26 July 2004.

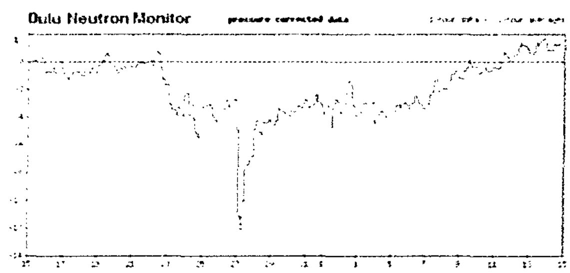

Figure 2. Oulu neutron monitor data showing the two impulsive FDs (22 and 26 July 2004) of Table 1.

Table 1 gives the estimated durations and decreases of all the FDs through 31 May 2005, followed by their estimated onset times at Earth based on times of associated increases in the IMF intensities (in italics) or, where available, their storm sudden commencements (SSCs). For each FD we list the date and time of first observation of a candidate associated CME observed in SMEI. Those are followed by the azimuth angles measured in degrees counterclockwise from north, the innermost SMEI observed solar elongation angles in degrees, and approximate angular speeds in degrees per hour measured on plots as shown in Figure 3. For SMEI CMEs through September 2004 we took the data from a catalog of observed SMEI CMEs compiled at AFRL by D. Mizuno and D. Webb. Data for more recent SMEI events were taken from other preliminary sources. The peak interplanetary magnetic field intensities in nanotesla accompanying each FD were taken from the MAG experiment on the ACE spacecraft. The LASCO dates and times of first observations and azimuth angles of candidate associated CMEs are taken from LASCO movies. For every FD we found a

good SMEI and a good LASCO CME candidate except for cases of data gaps (DGs). These associations are preliminary.

Table 1. Impulsive FDs and Associated SMEI CMEs

Date	Dura. Days	Decr. %	SSC UT	SMEI Date	SMEI UT	Azi. Deg.	Inn. Elg.	Speed Deg/hr	LASCO CME Date/Time, Azi.	IMF NT
2003 20 Mar	1	2	0444	19 Mar	1901	336°	22°	0.67	19/0230; halo	12
08 Apr	7	3	0111	07 Apr	1640	071°	75°	0.93	05/1450; 105°	16
29 May	5	8	1224	28 May	1653	284°	32°	1.76	28/0050; halo	29
21 Oct	>3	4	*1000*	20 Oct	0430	108°	29°	0.71	18/1530; halo	12
24 Oct	>5	3	1524	24 Oct	0652	101°	71°	3.37	23/0854; 053°	34
29 Oct	7	20	0611	28 Oct	1303	297°	21°	2.57	28/1054; halo	47
15 Nov	5	5	*0400*	14 Nov	0511	129°	23°	1.31	13/0930; 049°	13
20 Nov	9	4	0803	19 Nov	0548	150°	50°	2.34	18/0850; halo	55
2004 06 Jan	6	5	*1700*	06 Jan	0023	117°	31°	1.92	DG*	17
22 Jan	6	7	0137	21 Jan	0348	133°	35°	0.71	20/0006; halo	28
03 Apr	3	2	1410	01 Apr	0942	NW	23°	--	DG	18
22 Jul	5	4	1036	21 Jul	1602	348°	30°	1.57	20/1331; halo	18
26 Jul	14	8	2249	<1736/26	DG	--	--	--	25/1454; halo	26
13 Sep	14	4	2003	13 Sep	1311	089°	78°	3.33	12/0036; halo	27
07 Nov	>2	11	1052	06 Nov	~1000	--		--	06/0131; halo	46
09 Nov	9	5	0930	--	--	--		--	07/1654; halo	40
05 Dec	8	4	0746	--	--	--		--	03/0026; halo	35
2005 02 Jan	6	4	*1200*						01/0054; halo	14
17 Jan	8	15	*0700*						15/0630; halo	35
08 May	7	5	*0500*						06/1728; halo	16
15 May	10	8	*0400*						13/1722; halo	55
29 May	5	3	*0700*						26/1506; halo	20

*Considerable activity at the same position angle as the SMEI event, but reliable association is not possible because of a LASCO data gap from 18:00 UT (4 Jan) - 09:00 UT (5 Jan).

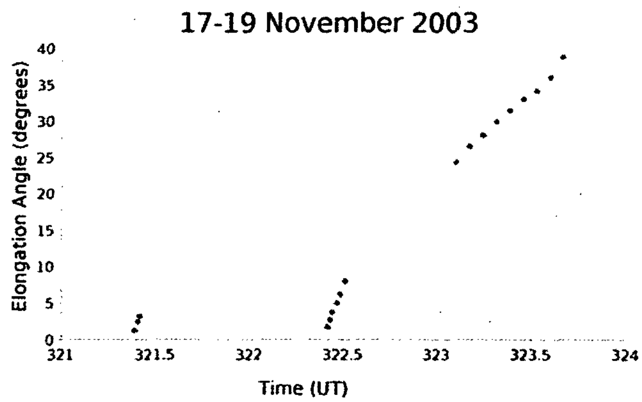

Figure 3. Plot of the observed solar elongation angles versus time for the combined LASCO (lower points) and SMEI (upper points) candidate CMEs associated with the 20 November 2003 FD of Table 1. Two LASCO CMEs are shown; the later one is appears to be a better fit to the SMEI CME and is listed in the Table. The SMEI CME angular speeds are determined from these plots.

3. Results

We found good candidate CMEs in the SMEI observations for each of the FDs of Table 1. A data gap probably precluded observation of the 26 July 2004 CME. We also found at least one good CME candidate in the LASCO data for each SMEI CME. Most of those are halo CMEs, as expected for those hitting the Earth [15]. We have plotted the time profiles of the observed elongation (Sun-SMEI-CME) angles of the

LASCO and SMEI CME leading edges. We attempted to match closely the azimuthal angles of the elongation measurements in the two instruments. The angular speeds of the SMEI CMEs range from ~0.7 to 3.4 deg/hr. Conversion of the observed angular elongations to distances from the Sun or from the Earth requires an assumption or model for the structures of the CMEs. One such model is a cone of 90° full width directed at the Earth, which was used for the study of the 29 May 2003 CME [4].

4. Conclusions

The good association of all the FDs with CMEs observed in SMEI shows that SMEI can be a useful forecast tool for FDs. The associations appear to preclude the possibility we raised in the Introduction that super-radial expansions of the CMEs could diminish their enhanced densities and render them invisible in SMEI.

Several points require further study. First is the question of how well the density enhancements of the SMEI CMEs correspond to the magnetic enhancements observed at Earth and how accurately their arrival times at Earth can be predicted. Transforming the observed elongation angles, angular speeds, and angular accelerations into linear distances, speeds and accelerations of the CMEs will require a much better understanding of the CME geometry than we have at present.

To validate the CME-FD association an inverse study to determine which Earth-bound SMEI CMEs of the Mizuno/Webb catalog produce FDs remains to be done. One surprising result of comparing the SMEI observations with the LASCO CMEs is that a significant number of SMEI CMEs do not have CME counterparts in the LASCO observations; we discuss this result in another paper in these proceedings. This then raises questions about the solar sources of those CMEs.

5. Acknowledgements

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